جامعة نيويورك أبوظبي
NYU | ABU DHABI

מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

Color centers

A novel technique to detect low-mass dark matter

Yossi Mosbacher, Micha Weiss, Hagar Landsman, Nadav Priel, Ilan Eliyahu,
Arik Kreisel, Ori Cheshnovsky, Ranny Budnik, *Gonzalo Martínez Lema**

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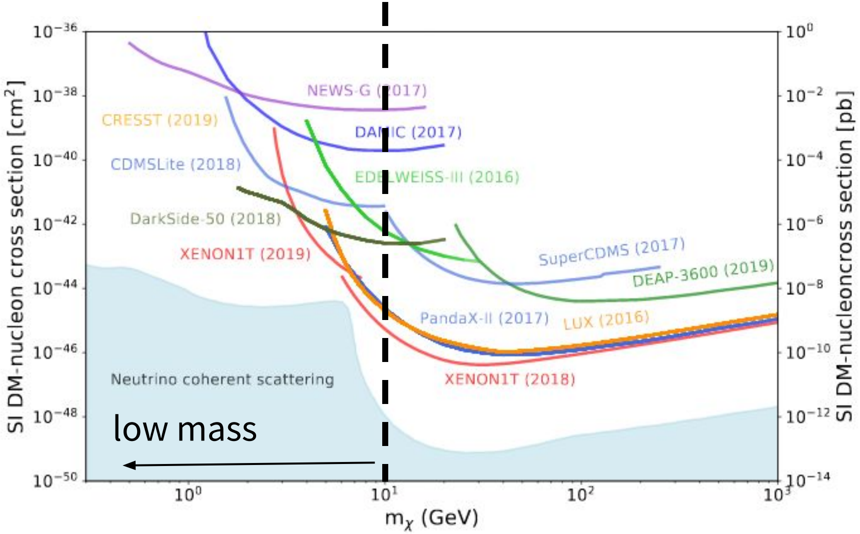
Status of dark matter searches

- In the ΛCDM model, dark matter comprises 85% of the matter in the universe
- WIMPs* are the most promising candidates
- Current searches focus on WIMPs with masses in the range 10^1 - 10^3 GeV/c^2



P.A. Zyla *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2020**, 083C01 (2020)

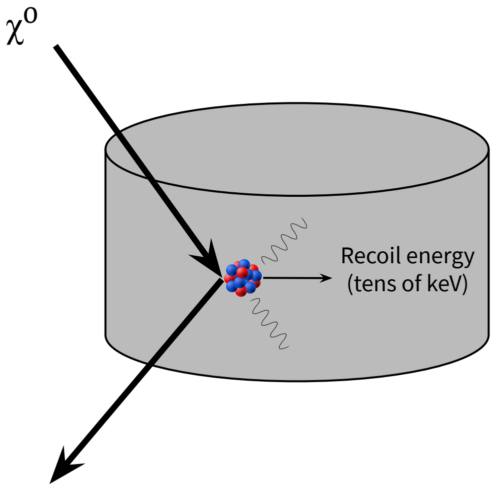
*Weakly Interacting Massive Particles

Extending the sensitivity of current searches

- The range of sensitivity of current experiments is limited by the threshold for signal production O(10 keV)$_{recoil}$ ~ O(10 GeV)$_{mass}$

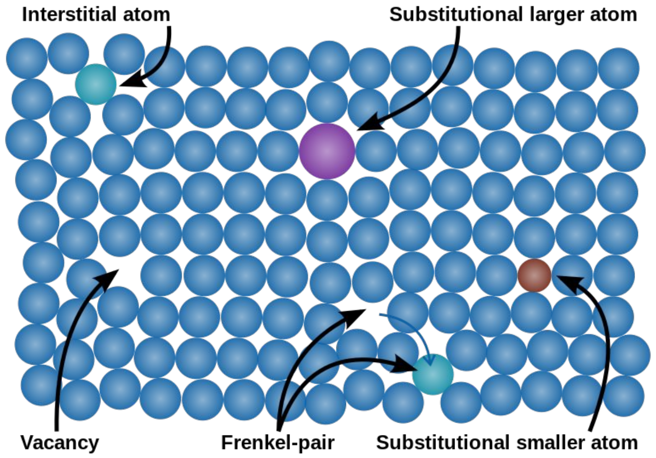
- The screening of lower masses requires different techniques with lower thresholds while keeping large masses

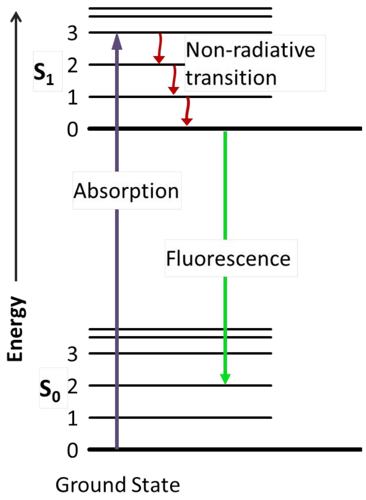
- We propose the use of Color Centers as a detection method of low-mass DM (≳10 MeV)



Color centers

- CCs are crystal defects in which an atom from the lattice is displaced and the gap is filled by an electron
- Trapped electrons can absorb UV-IR light and de-excite by emitting phonons and a fluorescence photon
- These defects are measurable to the single-defect level
- They are stable at room temperature
- Production threshold O(10 eV) -> O(10)$_{mass}$ MeV
- They can be produced by γ and neutron radiation





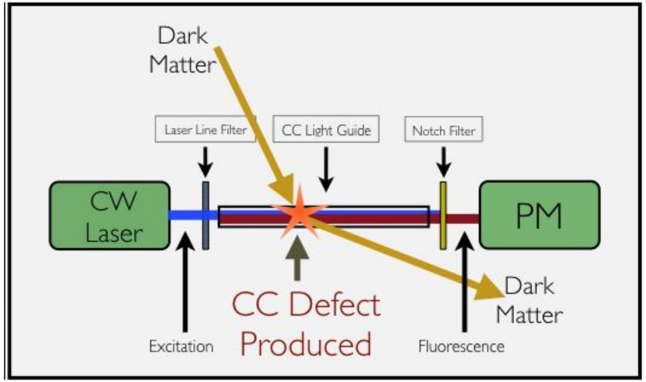
Conceptual detector features

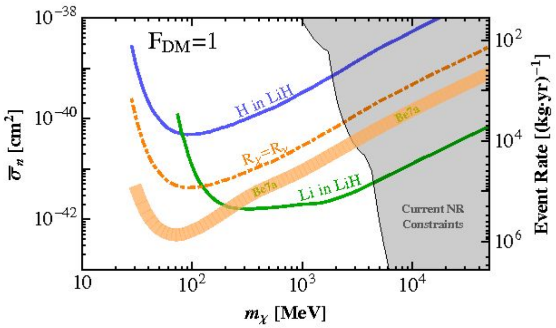
- Illuminate the crystal with the specific absorption wavelength -> measure fluorescence
- The full volume of the crystals can be used, as they are transparent to optical photons
- Easily scalable. Large masses available
- Sensitivity well below current limits for this mass range

Direct Detection of Light Dark Matter and Solar Neutrinos via Color Center Production in Crystals

Ranny Budnik, Ori Chesnovsky, Oren Slone, Tomer Volansky

1705.03016

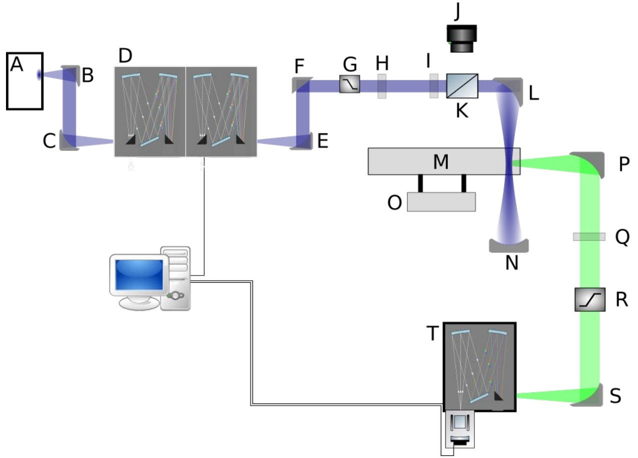


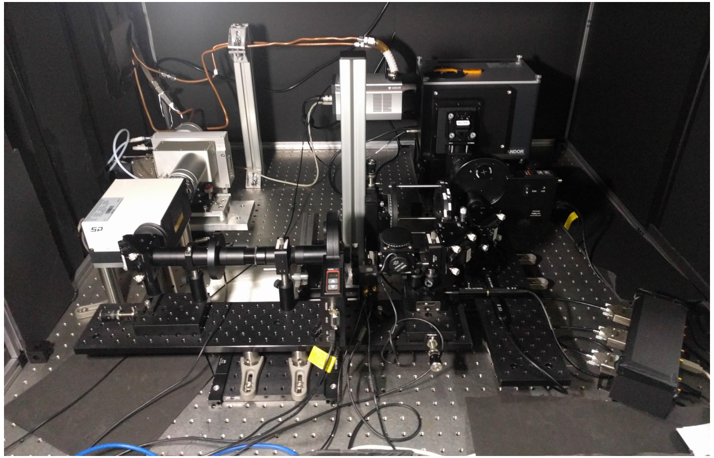


Our R&D project

- First step towards a DM detector
  - Optical setup to measure fluorescent spectra
  - Aimed to determine the best crystal candidate
- Designed to be versatile
  - Possible to explore a range of crystals
  - Wide range of excitation wavelengths

Crystal
LiF
MgF_2
CaF_2
BaF_2
MgO
Al_2O_3
ZnO
SiO_4
$LiNbO_3$
$LiTaO_3$

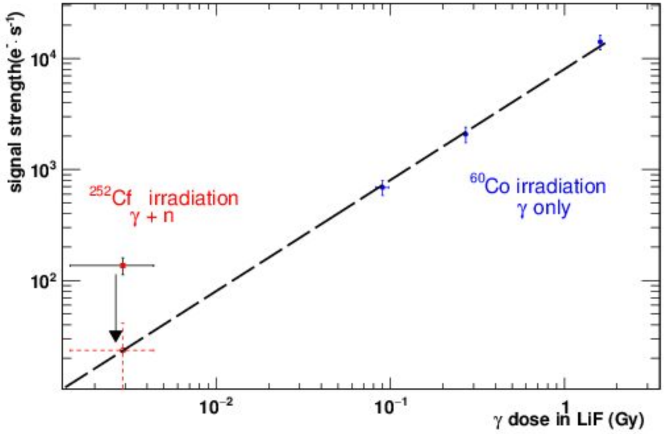


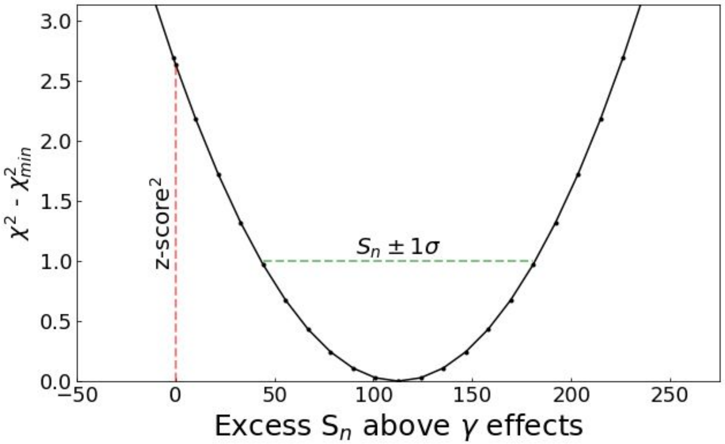


Strategy to find suitable crystals

- ^{60}Co source (γ, bkg) for 3 different doses*
  - Measure signal strength as a function of γ dose
- ^{252}Cf source (n + γ, sig + bkg) for 1 dose*
  - Measure signal strength and compare with the prediction based on γ dose

E (MeV)	^{60}Co	^{212}Cf
γ	1.2	0.8
n	X	2.3



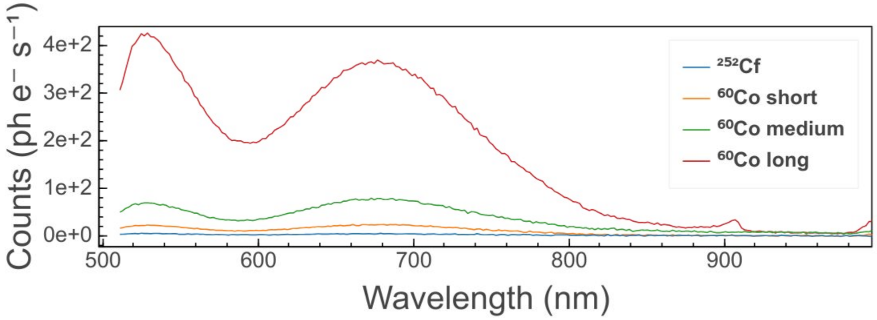


1902.10668

*Dose calculated from Fluka simulation

Fluorescence measurements

- Compare post- and pre-irradiation fluorescence spectra
- Fit data to a suitable model to extract signal strength



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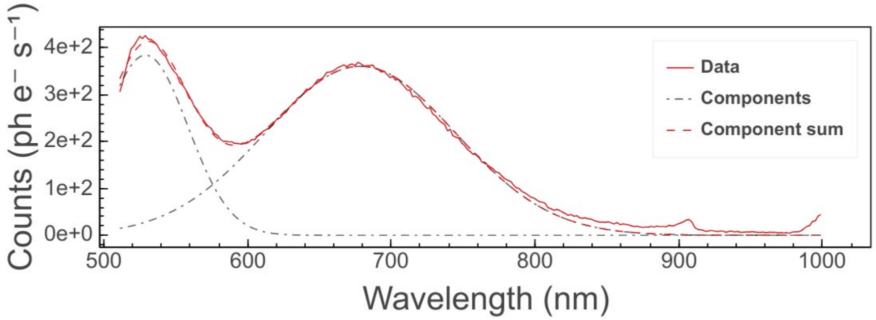


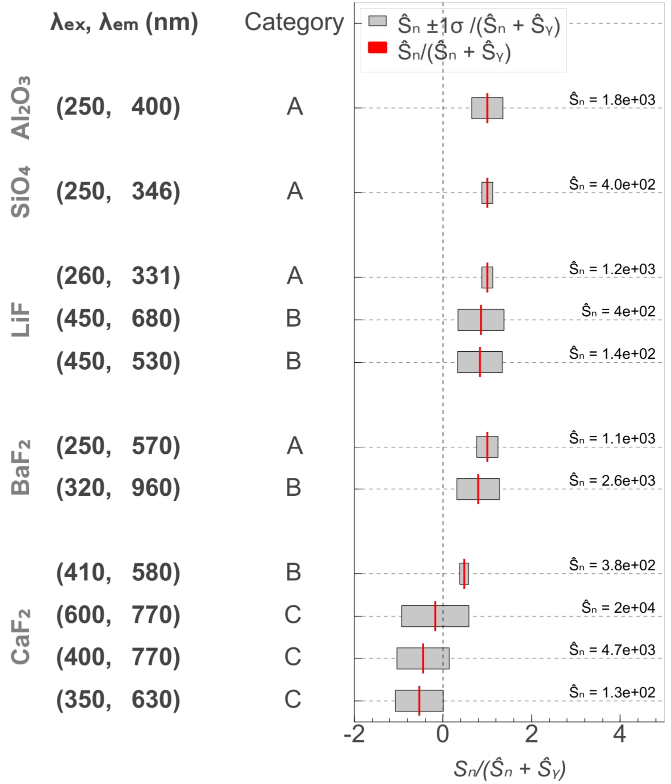
Wide band spectroscopic response of monocrystallines to low dose neutron and gamma radiation

Yossi Mosbacher, Micha Weiss, Hagar Landsman, Nadav Priel, Ilan Eliyahu, Arik Kreisel, Offir Ozeri, David Hershkovich, Ori Cheshnovsky, Ranny Budnik

Preliminary results

Preliminary

- Classification of CCs:
  - ***A***: signal increase produced by n, but not by γ
  - ***B***: signal increase produced by both n and γ with more than 1 σ significance
  - ***C***: signal increase compatible with γ-only production of CCs



[1902.10668](https://arxiv.org/abs/1902.10668)

Thank you

Backup slides

Next steps

- Discard thermal neutron contributions to observed signals
- Study a broader range of crystals
- Irradiations with lower-energy neutrons, for a closer representation of low-mass DM
- Develop a CC removal procedure (annealing) to keep optimal sensitivity over time
- Build a prototype detector for the best candidate found

Advantages and challenges

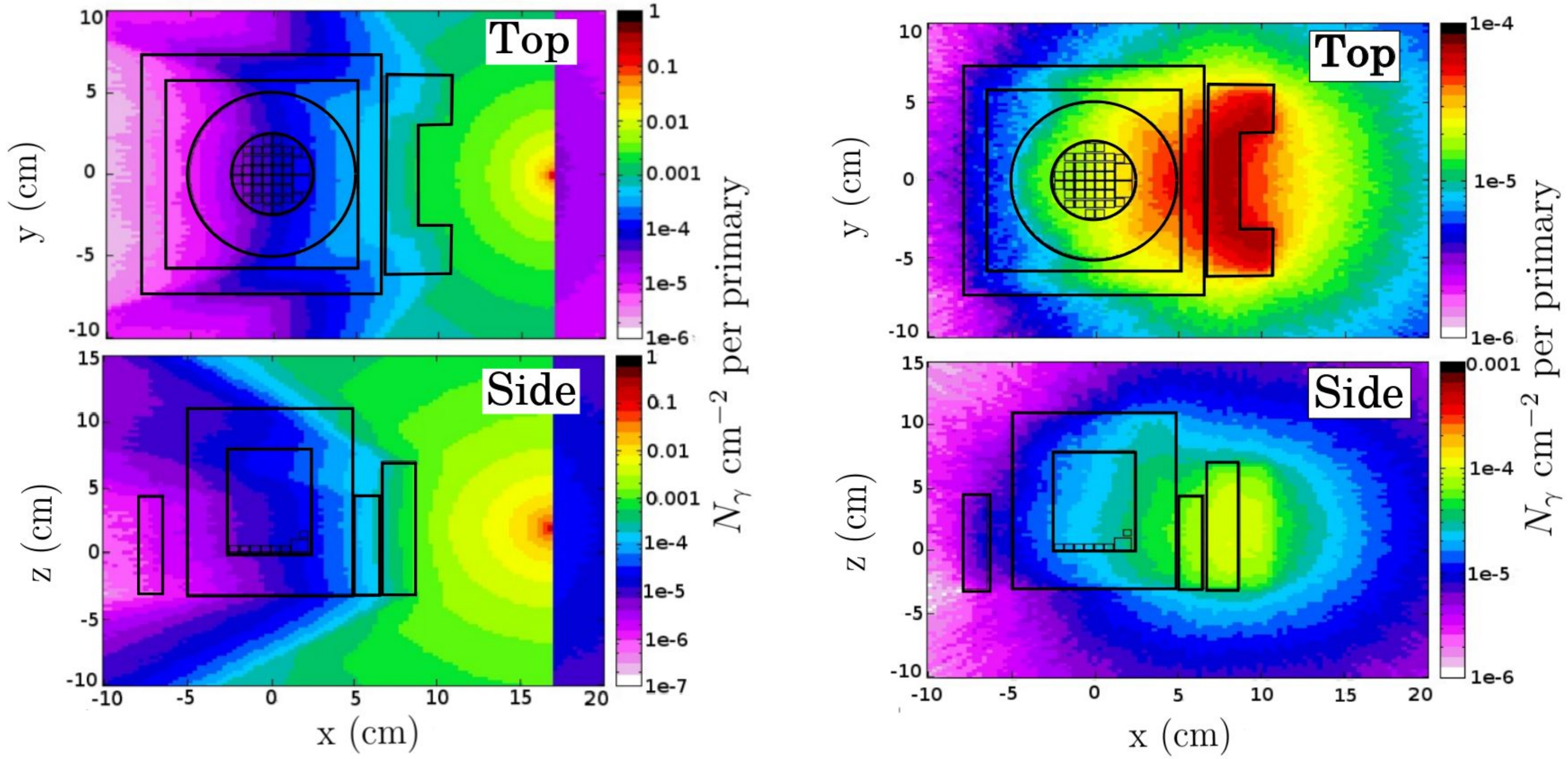
- Advantages
  - Color Center are long lived and not destroyed by measurement, minimizing readout noise
  - Optical photons have very large mean free paths in many materials, allowing for large volume detectors
  - Fluorescence photons are easily separated from excitation photons, increases sensitivity to small number of color centers
  - Large mass to readout-device ratio. Many single crystals are commercially available in kgs of mass
- Challenges
  - Very difficult to study defect creation and annihilation mechanisms
  - Hard to say ahead of time which crystals will be best, theory is limited. Most of the crystals being studied will not be useful
  - Existing color centers are difficult to remove
  - Can have low production efficiency at low recoil energies

Crystals and irradiation times

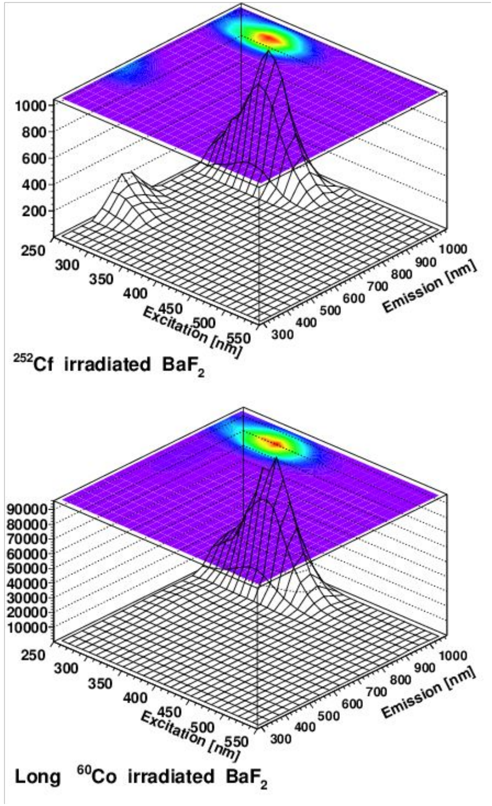
Crystal	Supplier	Side (mm)	Samples
LiF	UC	5	4
MgF_2	UC	5	5
CaF_2	UC	5	4
BaF_2	UC	5	4
MgO	PS	5	4
Al_2O_3	GV	10	4
ZnO	PS	5	4
SiO_4	UC	5	4
$LiNbO_3$	UC	5	3
$LiTaO_3$	UC	5	3

Irradiation	Source	Duration [hour]	D_γ [mGy]
Neutron	^{252}Cf	64.3	2.90 ± 0.75
γ_{short}	^{60}Co	1	90 ±15
γ_{medium}	^{60}Co	3	270 ±41
γ_{long}	^{60}Co	17.8	1600 ±240

Gamma flux

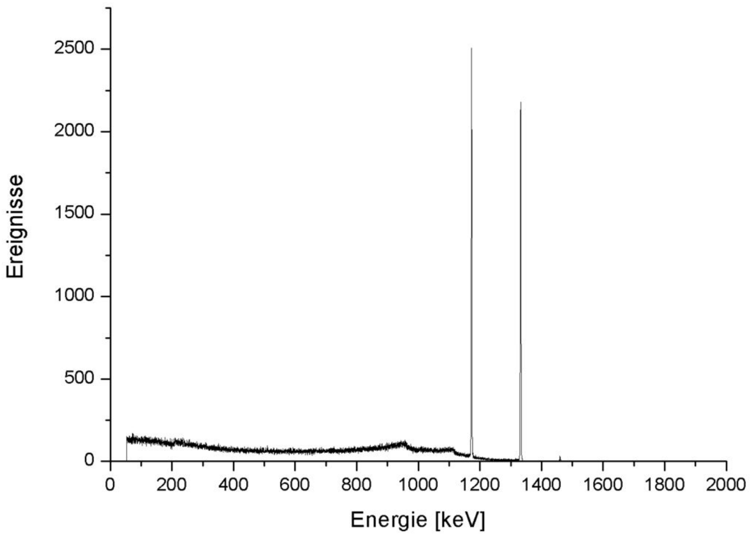

Top
Side
y (cm)
z (cm)
x (cm)
N_γ cm^{-2} per primary
1
0.1
0.01
0.001
1e-4
1e-5
1e-6
1e-7
0.001

Some signals

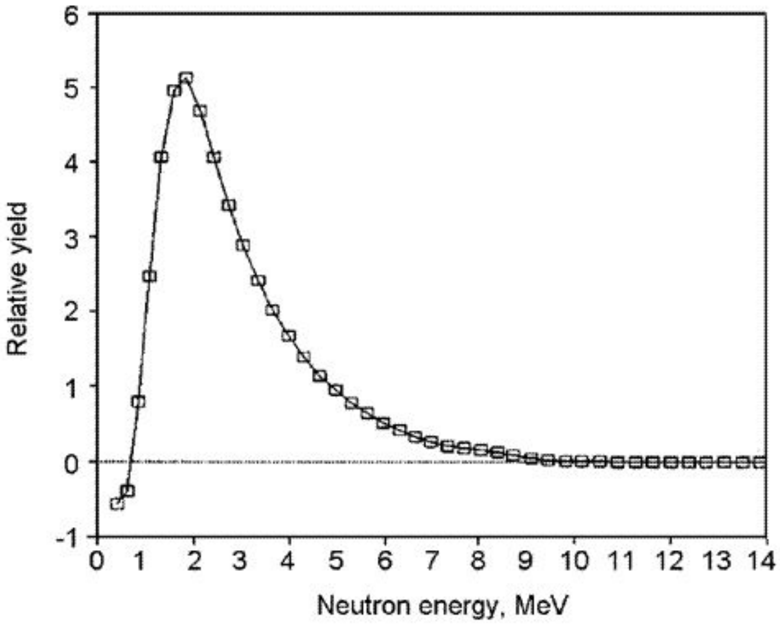


Sources energy spectra

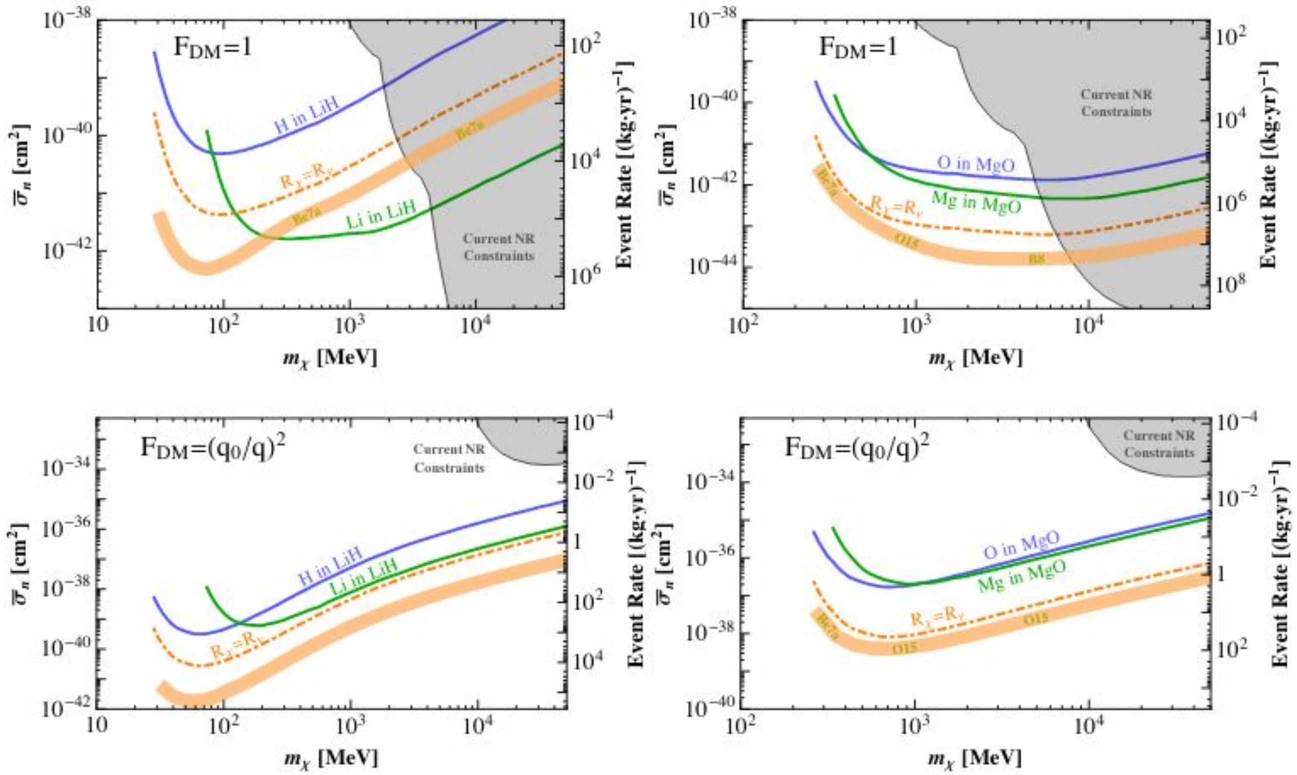
^{60}Co



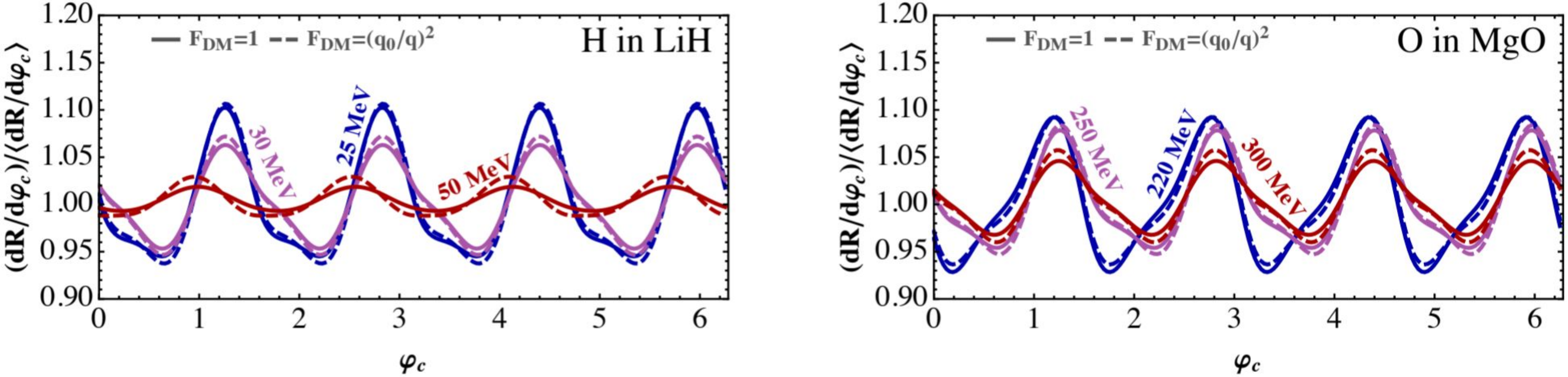
^{252}Cf



Sensitivity



Modulation



H in LiH
$F_{DM}=1$ $F_{DM}=(q_0/q)^2$
25 MeV
30 MeV
50 MeV
$(dR/d\varphi_c)/\langle dR/d\varphi_c \rangle$
φ_c
O in MgO
220 MeV
250 MeV
300 MeV